LA-UR -77-2390

MASTER

TITLE: RECENT WORK ON NORMAL AND SUPERCONDUCTING INDUCTIVE ENERGY STORAGE SWITCHING AT THE EFREMOV INSTITUTE, LENINGRAD, USSR

Conf-771029--33

AUTHOR(S): M. D. Machalek

SUBMITTED TO: 7th Symposium on Engineering Problems of Fusion Research, Knoxville, TN, October 25-28, 1977

los alamos scientific laboratory

of the University of California

LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

RECENT WORK ON NORMAL AND SUPERCONDUCTING INDUCTIVE ENERGY STORAGE AND SWITCHING AT THE EFREMOV INSTITUTE, LENINGRAD, U.S.S.R*

M. D. Machalek
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Introduction

The laboratories for normal and for superconducting inductive energy storage of the D. V. Eframov Scientific Research Institute of Electrophysical Apparatus (NIIEFA) are presently concentrating their efforts on producing coils for the new Soviet 2-5 TeV ring accelerator and producing coils and switches for the newest, largest Soviet tokamak "T-10M." Designs for "T-10M" must be complete by early to mid-1978 and operating hardware must be delivered to Moscow by mid-1979. Although the Efremov Institute has an ongoing program of general research into inductive energy storage and switching, present efforts have become focused onto the practical task of making "T-10M" operational.

Superconducting Inductive Energy Storage and Switching

Although superconducting energy storage devices of conventional design have been produced at NIIEFA, an innovative design utilizing a pair of coils is presently being built. The coils will be charged in series and discharged in parallel, analogous to a Marx bank. The aim is to produce a compact superconducting system capable of $\sim$100 kA output current. A working model should be tested by the end of this year.

A second innovative design is that of miniaturized superconducting switches.[1] These devices are basically 25 mm wide Nb-Ti foil of $\sim$20 μm thickness folded back and forth 150-250 times over a length of $\sim$100 mm. Glass fibre cloth insulates the layers and the units are potted in epoxy resin. Although these switches have a relatively high resistance of 20-25 Ω each, their small size allows them to be utilized in parallel. Working currents per unit are on the order of 2-3 kA. Quenching is presently done by means of an overcurrent pulse, but much work has been done on the technique of magnetic field quenching with its advantage of electrical separation of the quenching circuit from the main circuit. The difficulties of field quenching are the shielding effects by the outer layers of superconductor of the interior of the switch.

Theoretical studies[2] are proceeding on designs for superconducting inductive energy coils which have no external fields, fields which would perturb diagnostic and control equipment and waste energy through eddy currents induced in nearby conductors. There appears a strong feeling among Soviet scientists that for large fusion reactors such field-free energy storage inductors are necessary. Optimization calculations have led to a design consisting of concentric ellipsoidal coil pairs. An experimental model is planned for next year.

At the present time essentially the entire effort of the superconducting laboratory at NIIEFA has been diverted to two projects, (a) the magnets for the 2-5 TeV ring accelerator for Serpukov and (b) the toroidal field coils for the "T-10M" tokamak. In the latter project the first problem is selection of the superconducting material for the tokamak coils.[3] The second problem is the selection of circulating or immersion cooling of the coils. The "T-10M" coils are presently envisioned as 24 coils of four pancakes each with total stored energy being 540 MJ. Switching will probably be some version of the miniaturized switches described above.

Normal Inductive Energy Storage and Switching

For several years now work has been proceeding at NIIEFA on a large, 20-MJ inductive energy store (II-20), possibly for powering a θ-pinch fusion experiment. Although the inductor itself (called IN-20) has yet to be built, much work has gone into development of the switches for the II-20 device. "Make" switches of spark-gap or contactor type are not being considered as all designs are aimed at breaking currents from inductive sources.

II-20 has a three-stage switching arrangement which will consist of (1) pneumatic rheostat (to reduce the current level), (2) a nonlinear resistor (to shape the current to better match load characteristics), and (3) an explosive breaker (to finally interrupt the current).

The pneumatic rheostat is basically a coil made of flat brass strip with a circular wiper moving down through the cylinder. Axial travel of the wiper is 4 cm, which occurs in 5-10 ms with air pressure of 10-15 atm. Electrical resistance varies from $\sim$ 0 to 20 Ω, with a resulting current reduction factor of 500.

The nonlinear resistor is simply a high purity iron conductor cooled to LN_2 temperature and then, with passage of current is passively heated to about 600°C. Resistance varies from $\sim$ 50 mΩ to 3.5 Ω, a factor of $\sim$ 70. The resistive unit has already gone through several design improvements.

The explosive switch is essentially a set of internally stepped steel rings stacked around a conducting tube, which itself is filled with paraffin, oil, and a string of explosive. With the detonation the conducting tube is driven outward and cut into successively different diameter rings. Paraffin pushed in behind the larger rings electrically seals the broken circuit and prevents arcs from developing. A current of 150 kA at 45 kV has been interrupted in a time of 50 μs, giving an energy of $\sim$ 1/3 MJ. Design parameters call for currents up to $\sim$ 200 kA and energies of $\sim$ 1 MJ.

A second type of explosive switch recently developed at NIIEFA consists of a cylindrical rod of sintered powdered conductor and powdered explosive. Copper powder is mixed with 100-micron size grains of explosive material in a ratio of 50%-50% by volume, or 90%-10% by weight. The mixture is annealed in hydrogen at 300°C and then sintered at 5000 atm by conventional powder metallurgy techniques. The rod is detonated and self-destructs at the appropriate moment interrupting the current. Resistance of the rod is $\sim$ 100 μΩ/cm. A test firing of a model interrupted the current in 10 μs, after which time an arc developed. Depending on the structure of the device, it is claimed the arc can be suppressed in as little as 100 μs.

Regardless of all the sophisticated switch development at NIIEFA, the breaker for "T-10M" is to be a simple pneumatically driven metal-to-metal switch. The design is envisioned as basically two side-by-side blocks of metal spanned by a bar of metal. Problems with the design relate to the lifetime of operation

*Work participated in during a 16-week scientific exchange visit under the auspices of the U.S. Energy Research and Development Administration.

(required to be at least 10,000 cycles) and the speed of operation (relating to energy to accelerate and then impact upon stopping moving parts of the switch). Contact metal needs to have high electrical conductivity, yet must not be so soft that it "hammers out" and distorts. Possible candidates are Be-Cu, Cd-Cu, and Cr-Cu. At present Cr-Cu is favored because its conductivity is 75%-85% that of copper, yet Cr-Cu is quite hard. The final selection will depend to a large extent upon what alloy is available in the Soviet Union at the time.

Conclusions

Various forms of switches for both normal and superconducting inductive energy storage have been devised and developed at NIIEFA. At the present time, however, a major portion of the efforts of the Institute in these fields is being applied to the design and construction of coils for tokamak "T-10M." The superconducting toroidal field coils (the design of which is still uncertain) will be switched by simple switches made of Nb-Ti ribbon. The normal coils for the poloidal field will be switched by a simple metal contactor breaker. As the "T-10M" project proceeds, perhaps some of the innovative inductive storage and switching work can continue and when "T-10M" is complete, the basic research can resume at full level.

References

1. V. A. Glukhikh, A. I. Kostenko, N. A. Monoszon, V. A. Tishchenko, and G. V. Trokhachov, "Results of Research into Superconducting Switches with High Specific Switching Capacity," Paper presented by A. I. Kostenko at the All-Union Conference on Engineering Problems of Thermonuclear Reactors, Leningrad, June 28-30, 1977.

2. S. A. Egorov and A. I. Kostenko, "On the Application of a Two Superconducting Ellipsoidal Coil System Without External Magnetic Field as an Inductive Energy Storage," Preprint B-0310, D. V. Efremov Institute (NIIEFA), Leningrad, 1976.

3. V. A. Glukhikh, A. I. Kostneko, N. A. Monoszon, G. V. Trokhachov, and E. A. Horn, "On the Selection of the Superconducting-Current-Carrying Element for the "T-10M" Installation," Preprint B-0322, D. V. Efremov Institute (NIIEFA), Leningrad, 1976.